B-27

INSTRUCTION MANUAL

472A

PRECISION STANDARDS CORPORATION

PSC

1701 Reynolds • Santa Ana, Calif. 92705 • (714) 546-0431

PRECISION INSTRUMENTS FOR SCIENCE AND INDUSTRY

PRECISION Standards CORP.

1701 REYNOLDS, SANTA ANA, CALIF. 92705

DC VOLTAGE CALIBRATOR

MODEL 472A

Serial_____

PRECISION STANDARDS CORPORATION

1701 Reynolds
Santa Ana, California 92705

Telephone - 714/546-0431

PRECISION Standards CORP.
1701 REYNOLDS, SANTA ANA, CALIF. 92705

SPECIFICATIONS

MODEL 472A

Output Voltage:		0 - 11V (4 terminal) 0 - 110mV
Output Current:		0 - 20ma on 11V range 10 ohm output resistance on 110mV range Short circuit protection provided.
Accuracy:	11V Range	± .0025% or reading ±2 PPM of range ± 10uV 23°C ± 2°C
	110mV Range	± .0025% of reading ± 1PPM of range ± 1uv 23°C ± 2°C
Line Regulation: (±10% line change)	11V Range	.0005% ± 5uV
	110mV Range	.0005% ± 5uV
Load Regulation:	11V Range	.0005% ± 10uV 0 - full load
Resolution:	11V Range	1uV
	110mV	.05uV
Noise & Ripple:	11V Range	30uV RMS
	110mV	2uV RMS
Stability:	11V Range	5PPM - 10uV/hour 10PPM - 15uV/day
	110mV Range	5PPM - 1uV/hour 10PPM - 1uV/day
Warm-up Time:		Operation in less than 10 seconds. 30 minutes for optimum performance.

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SECTION I

DESCRIPTION

1.1 The Model 462A/472A DC Voltage Calibrator provides two DC output ranges simultaneously, 0 - 11 volts and 0 - 110mV. All circuits are solid state and contain no mechanical or electronic choppers. Double contact switches are provided in critical areas to minimize offset errors due to contact resistance.

1.2 EQUIPMENT DESCRIPTION

The Model 462A/472A Calibrator is a light weight portable instrument designed for bench operation. Rack mounting brackets are available on order. The top and bottom covers are removable to expose the internal circuits for calibration and maintenance.

1.3 FRONT PANEL CONTROLS & FEATURES

POWER switch S1 is a two position rotary with OFF and ON positions. One decimal lamp is illuminated when POWER switch is ON.

POLARITY switch S2 is a three position rotary switch that reverses the output polarity without the need of reversing the output leads. The OFF position shorts out the positive and negative load terminals.

The KELVIN VARLEY DIVIDER consists of six decades with 0-10 capability on first and last decades. Remaining decades are 0-9. The switches are designated from left to right S3 through S7. The last decade, a potentiometer, is designated as R107.

SECTION II

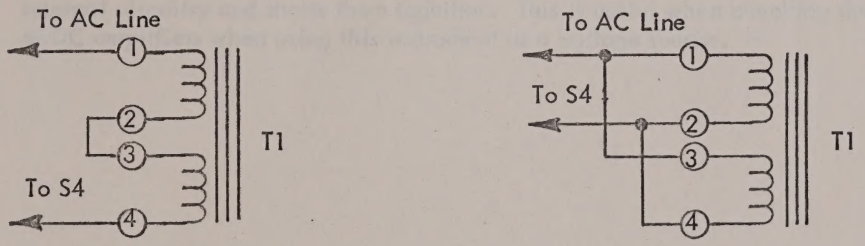
OPERATION

2.1 INSPECTION

After unpacking, inspect the equipment. If shipping damage is found, report the facts to the shipping agency and to us. If equipment fails to operate as specified, check all connectors, cables and fuse. Should equipment fail to operate satisfactorily during the warranty period, follow the procedure outlined in the warranty.

2.2 PRIMARY AC POWER

Unless requested otherwise, this instrument is supplied wired for 115 volts AC operation. Should operation at 230 volts AC be required, remove the top and bottom covers and reconnect primary supply jumpers as shown in Figure 2.1 and install a 1/8 amp slo-blo fuse in the fuse receptacle.



(a) 230 volt AC operation, use 1/4 amp fuse.

(b) 115 volt AC operation, use 1/2 amp fuse.

Figure 2.1. Power Transformer Wiring

2.3 PRECAUTIONS

The floating input should not exceed 200 volts above or below chassis ground.

2.4 ELECTRICAL ZERO ADJUSTMENT

Allow a minimum of 30 minutes warm-up. Dial decades to zero and measure the output voltage with a micro voltmeter.

2.5 For optimum accuracy it is urged that copper to copper leads be used and keep all connections clean to minimize errors dur to thermals.

For best voltage accuaracy at the load, use the 4 terminal capability.

SECTION II

OPERATION

2.6 RIPPLE

Ripple specifications are met with the POS or NEG terminal tied to GND. This calibrator may be floated, but higher ripple may be expected.

2.7 POLARITY

The polarity may be reversed or turned off without the need of turning instrument power off. If a few micro volts of error are noted in one polarity as opposed to the other. Check the zero by dialing the decades to zero and measuring the output with a micro voltmeter or galvo with at least 30uV full scale sensitivity. If adjustment is required, refer to the calibration and maintenance section of the manual. The OFF position of the POLARITY switch electrically disconnects the load terminals from the internal circuitry and shorts them together. This is useful when checking the zero shift of DC amplifiers when using this instrument as a voltage source.

THEORY OF OPERATION

3.0 This calibrator derives an adjustable voltage through a Kelvin-Varley potentiometer driver by a stable reference. The output of the Kelvin-Varley potneiometer is buffered by a unity gain amplifier (GPA-1) or "bootstrapped" to provide power capability to the output terminals. The amplifier's common and output are brought out to the load terminals while NEG input and KVD LO are brought out to the "sense" terminals.

3.1 The 110mV range is provided by a 10ma resistance divider.

For theory of operation of the RS-11 reference and the GPA-1 amplifier, refer to the appendix in this manual.

SECTION IV

CALIBRATION

4.0 The Model 462A/472A is calibrated and checked in the following sequence:

a. Zero calibration

b. KVD calibration

c. Full scale voltage calibration (both ranges)

d. Polarity test

e. Linearity test

CAUTION

Do not move any internal adjustments until the need has been established. Inadvertant movement of internal adjustments can lead to extensive and unnecessary calibration.

4.1 REQUIRED CALIBRATION EQUIPMENT

a. Precision voltmeter, PSC Model SS1000 or ESI Model 1045 or equivalent

b. 500 ohm, 5%, 1/2W Carbon Resistor

c. LO Thermal copper clips and leads

4.2 ZERO TEST

Allow 30 minutes warm-up. Dial the KVD decades to zero. Measure the output voltage. Adjust R27 ZERO ADJUST on the GPA-1 amplifier for a zero reading at the terminals.

4.3 KVD ALIGNMENT TEST

a. Dial 1.00000 Volt and null the SS1000 or ESI 1045.

Re-dial 1V by dialing 0.999910 . Error should be less than 10uV or 1PPM of full scale. If adjustment is required, adjust R41 located on rear of first decade. Access is gained by removing the amplifier/reference mother board from the 4 standoffs.

4.3 KVD ALIGNMENT TEST (continued)

b. Dial 0.10000 and null out as in Step a. Re-dial 0.099910. Adjust R55 if error is greater than 10uV.

c. Dial 0.001000 and null out as in Step a. Re-dial 0.009910. Adjust R69 if error is greater than 10uV.

d. Repeat Steps a. through c. if adjustments have been made.

4.4 Dial full scale voltages (11V). Check accuracy against specification in this manual. If adjustment is required, adjust R26 CAL on the RS-11 board assembly.

4.5 With full scale voltage dialed, reverse the polarity and measure the output voltage. The voltage should equal to ± zero offset of the POS polarity.

4.6 LINEARITY TEST

Dial and measure 1.11111V, 2.22222V, etc., and compare results to specified accuracy.

SECTION V

MAINTENANCE

5.1 GENERAL

When operated within the specified limits, the calibrator should maintain high performance standards for an extended period. No preventive maintenance is required except for routine cleaning. If the instrument shows signs of erratic or out-of-tolerance measurements, calibrate the meter as required (Section IV).

5.2 DISASSEMBLY

To remove the top cover, remove eight screws (three on each side of the instrument and two on the top) and lift cover from the instrument. To remove the bottom cover, remove eight screws on the bottom of the instrument and lift the cover from the instrument.

NOTE

It is not necessary to remove the screws retaining the rubber feet.

5.3 REPLACEMENT OF KVD RESISTORS

Each decade switch of the Kelvin-Varley Divider contains a matched set of precision resistors that seldom require replacement. However, if a decade resistor is found to be defective, the complete decade switch assembly must be replaced. When ordering replacements, include the model and serial numbers.

5.4 GPA-1 AND RS-11 REPAIRS

Special test equipment is used to determine the final values of many components on the GPA-1 and RS-11 plug-in cards. This equipment is not normally available in the field, therefore, it is recommended that the cards be returned to the factory for repair when the following components are faulty:

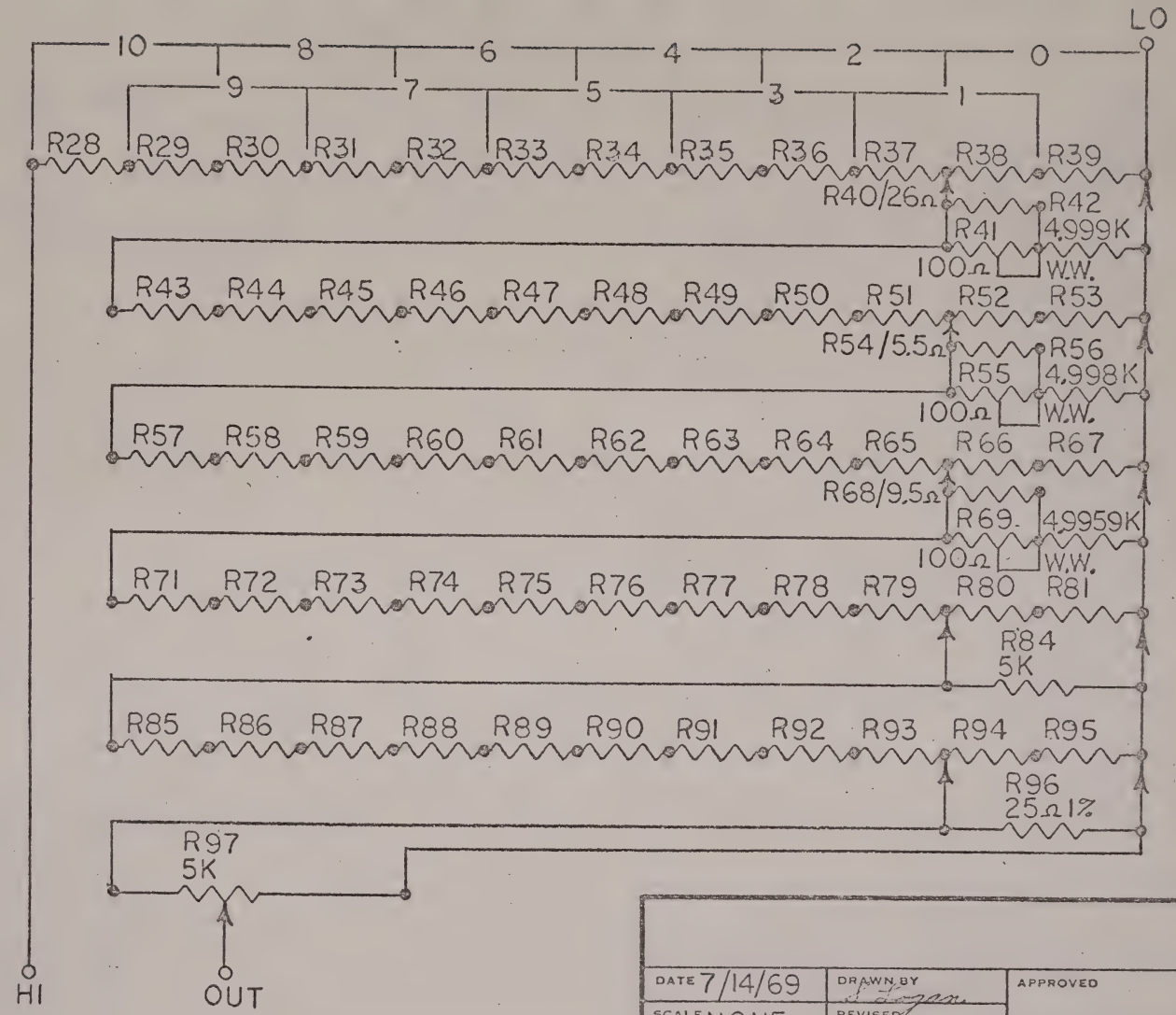
a. Components designated as "select on test".

b. Precision wire-wound resistors.

c. Zener diodes.

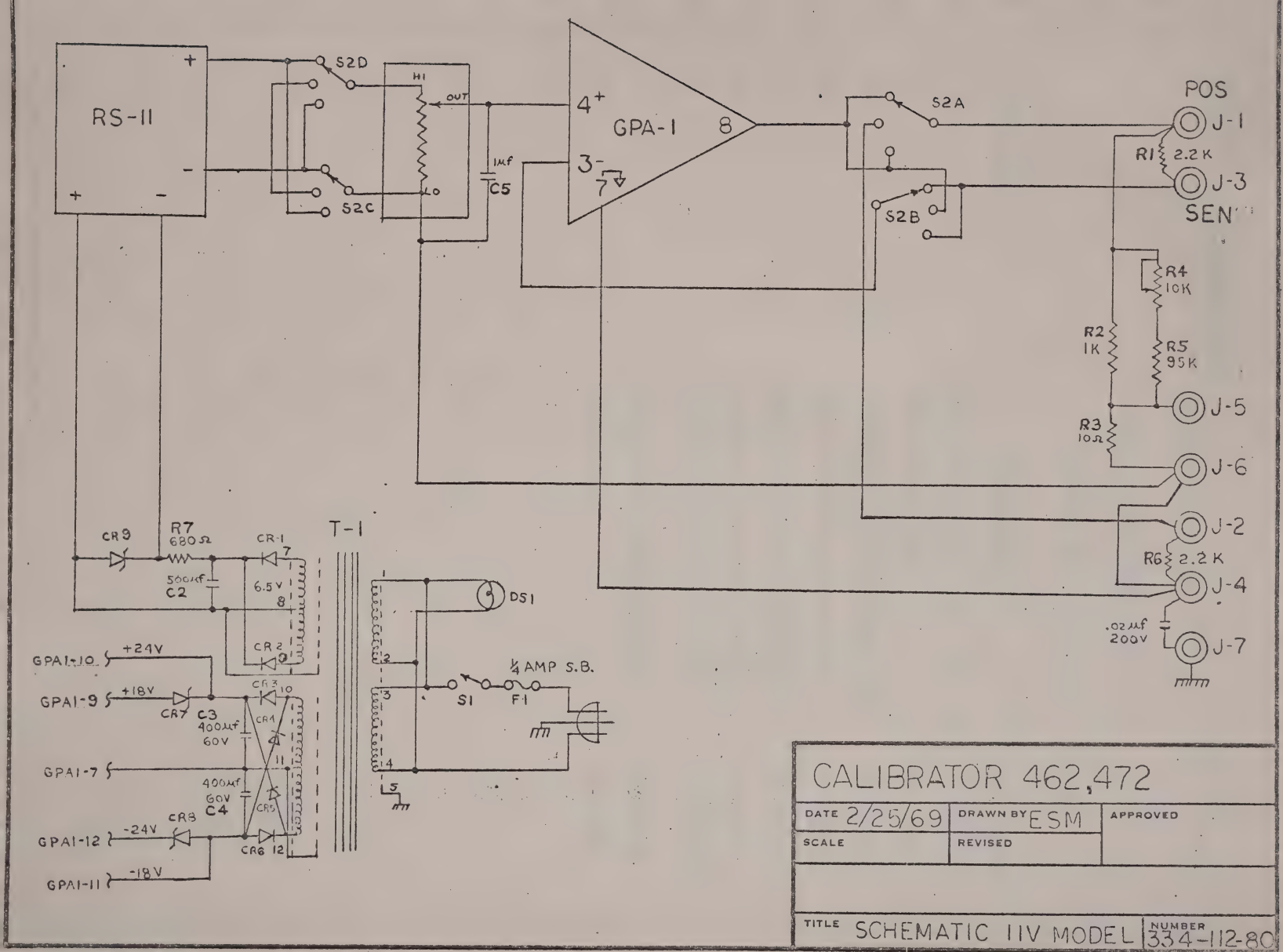
d. Matched components (transistors, resistors, etc.).

e. Dual-transistor Q5 or TC bridge resistors on the RS-11 card.



DATE 7/14/69	DRAWN BY T. Logan	APPROVED
SCALE NONE	REVISED	
MODEL 472/462		
TITLE KVD SCHEMATIC		NUMBER 334-111-80

FULLERTON NO. 1100 OPALINE



CALIBRATOR 462,472		
DATE 2/25/69	DRAWN BY ESM	APPROVED
SCALE	REVISED	
TITLE SCHEMATIC IIV MODEL		NUMBER 334-112-80

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REPLACEMENT PARTS LIST

MODEL 462

Reference	Description	Stock Number
T1	Transformer, Power	96-47-721
S1	Switch, Rotary, Power	334-316-30
S2	Switch, Rotary, 4 pole, 3 pos., N.S.	95-80-699
S3	Kelvin-Varley Divider Assembly #1	334-104-80
S4	Kelvin-Varley Divider Assembly #2	334-106-80
S5	Kelvin-Varley Divider Assembly #3	334-107-80
S6	Kelvin-Varley Divider Assembly #4	334-108-80
S7	Kelvin-Varley Divider Assembly #5	334-109-80
R97	Potentiometer, 5K	27-0009

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REPLACEMENT PARTS LIST

AMPLIFIER MOTHER BOARD

Reference	Description	Stock Number
1 each	Amplifier, Mother Board Assembly	334-100-80
1 each	Amplifier, P.C. Mother Board	334-100-30
CR1, CR2, CR3, CR4, CR5, CR6	Diode, Rectifier	94-02-600
CR7, CR8	Diode, Zener, 5.5V	94-16-055
CR9	Diode, Zener, 1N4750	92-47-500
C2, C3, C4	Capacitor, Elect., 500uf, 50V	61-50-508
R7	Resistor, FC, 1/2W, 5%, 680 ohms	86-05-348
R2	Resistor, WW, 1K ohms, .02%	15-13-500
R3	Resistor, WW, 10 ohms, .02%	15-13-010
R5	Resistor, WW, 95K, .1%	15-14-095
R4	Resistor, Variable, 10K	88-15-421
1 each	Connector	70-20-221
DS1	Lamp, Neon, Decimal	42-0001
1 each	Lamp Housing	60-0002
1 each	Spring	47-0023
1 each	Ring, Retaining	47-0024
4 each	Rubber Feet	47-0017

SECTION VI

WARRANTY

The PRECISION STANDARDS CORPORATION warrants each instrument to be free from defects in material and workmanship. The instrument must be returned to the factory with shipping prepaid and a complete report of the difficulty. This warranty is good for one year from the shipping date.

SHIPPING DAMAGE

If there is any damage to the instrument upon receipt, report this to the transportation claim agent immediately.

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REFERENCE SUPPLY

RS-11

APPENDIX

RS-11 REFERENCE SUPPLY

1.0 The reference supply, shown in block form in Figure 3.4, consists of a differential amplifier, reference diode, voltage-setting divider and temperature-compensating bridge. The output from this supply, 11 volts, is selected by the REFERENCE switch and routed to the Kelvin-Varley Divider.

Refer to the RS-11 schematic. The amplifier has a single differential stage (Q5) and a cascaded emitter follower output (Q3 and Q4). Transistor Q2, in combination with CR1, CR2 and R4, provides a stable, low TC (temperature coefficient) current source for the output section of Q5. This arrangement provides high gain and supply isolation. Q1 provides constant current to CR1 and CR2. CR1 is a low TC Zener and CR2 compensates for temperature changes in the base-emitter junction of Q2.

The bridge, formed by R10 through R20, CR5 and CR6, furnishes an output voltage that is a function of temperature. This correcting voltage, adjustable at R16, adds (or subtracts) a small amount to the reference voltage for precise temperature compensation. The reference diode is CR7, with R21 providing a stable current. Resistors R22, R23 and R24 make up the voltage-setting divider, with R25 and R26 providing a fine voltage adjustment.

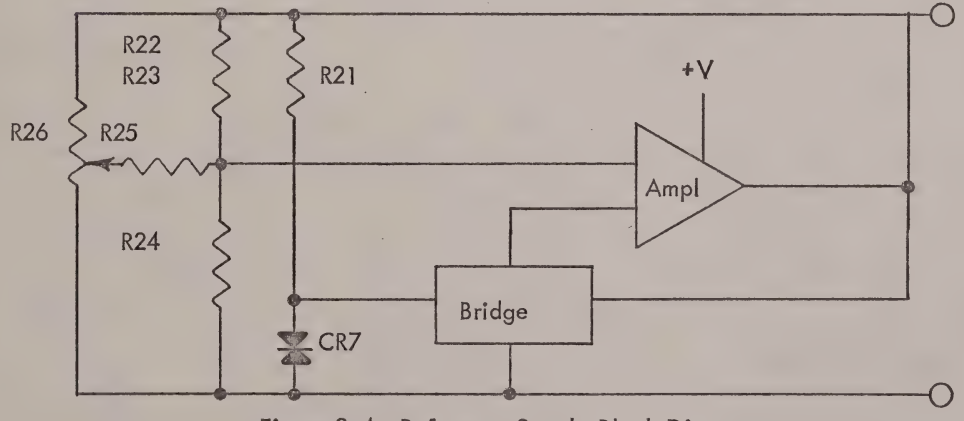
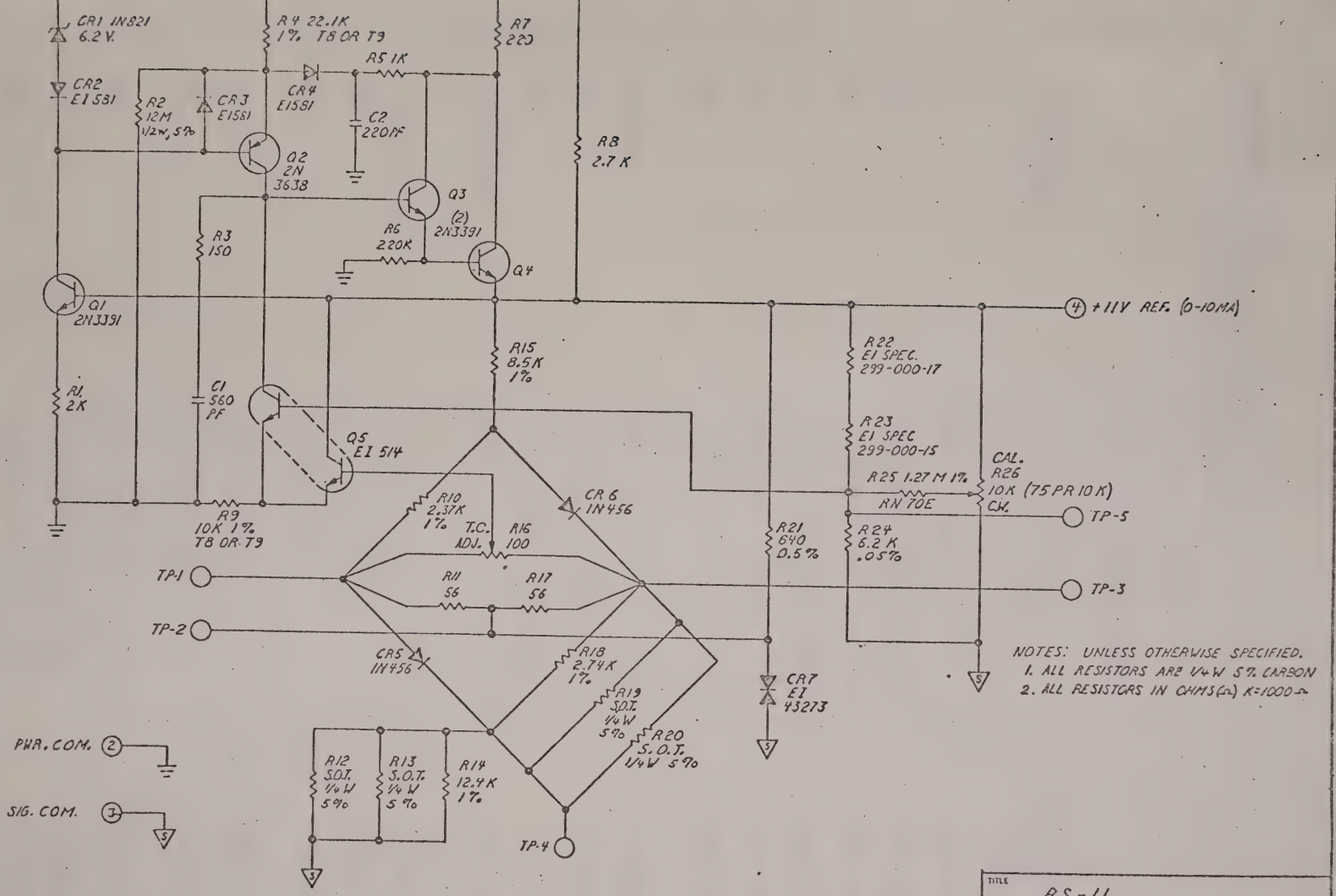


Figure 3.4 Reference Supply Block Diagram

1.1 Kelvin-Varley Divider

The KVD presents a constant 22 kilohm load to the selected reference regardless of the decade switch positions. The divider consists of six resistive decades that are controlled by decade switches S5 through S10. East switch position selects a voltage corresponding to the decimal value indicated by the position number in the readout. Selected voltages from each decade are additive and the total output voltage can be read directly from the readout dials.



TITLE: RS-11 REF. SUPPLY			
	SIZE: C	DRAWING NO.: 331-103-(80)	REV: A
SCALE: NONE	WEIGHT	SHEET 1 OF 1	

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RS-11 REFERENCE

REPLACEMENT PARTS LIST

Reference	Description	Stock Number
R5	Resistor, FC, 1K, 1/4W, 5%	86-04-364
R1	Resistor, FC, 2K, 1/4W, 5%	86-04-392
R8	Resistor, FC, 2.7K, 1/4W, 5%	86-04-408
R6	Resistor, FC, 220K, 1/4W, 5%	86-04-596
R2	Resistor, FC, 12 meg, 1/2W, 5%	86-05-772
R16	Potentiometer, 100 ohms	88-20-306
R26	Potentiometer, 10K, Helitrim	88-20-829
CR5,CR6	Diode, 1N456	92-04-560
CR1	Diode, Zener, 1N821	92-08-210
CR7	Diode, Reference PSC 43273	94-43-273
CR2,CR3,CR4	Diode	94-45-581
Q1,Q3,Q4	Transistor, 2N3391	91-33-910
Q2	Transistor, 2N3638	91-36-380
Q5	Transistor, 514	94-60-240
C1	Capacitor, 560 PF	48-10-561
C2	Capacitor, 220 PF	48-10-221
R21	Resistor, WW, 640 ohm, .5%	12-12-300
R24	Resistor, WW, 6.2K, .05%	12-15-621
R10	Resistor, MF, 2.37K, 1%	83-07-490

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RS-11 REFERENCE

REPLACEMENT PARTS LIST

Reference	Description	Stock Number
R18	Resistor, MF, 2.74K, 1%	83-07-499
R15	Resistor, MF, 8.5K, 1%	83-07-532
R9	Resistor, MF, 10K, 1%	83-07-533
R14	Resistor, MF, 12.4K, 1%	83-07-536
R4	Resistor, MF, 22.1K, 1%	83-07-555
R25	Resistor, MF, 1.27 meg, 1%	83-58-900
R3	Resistor, FC, 150 ohm, ¼W, 5%	86-04-280
R7	Resistor, FC, 220 ohm, ¼W, 5%	86-04-296

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GPA-1 AMPLIFIER

APPENDIX

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SECTION I
DESCRIPTION

A1.1 INTRODUCTION

The Model GPA-1 General Purpose Amplifier is a direct-coupled plug-in amplifier than can be used with external (or internal) add-on impedances as an integral part of a larger analog circuit. The impedance configuration determines the gain and function of the integrated circuit. The amplifier input is differential with high common mode input impedance, providing good operation and low current uncertainties from high resistance sources. DC drift with temperature is minimized within the amplifier; however provision is made for installing temperature compensating diodes on the input pair transistor heat sink as part of an external temperature compensation bridge. If the temperature compensation circuit is not used, the amplifier plug-in boards can be exchanged without re-calibration. If the temperature compensation circuit is used, it should be readjusted. The amplifier is normally used without chopper stabilization. (There is a patent pending on circuits used in the amplifier.)

A1.2 FUNCTION

The amplifier can operate in an inverting or non-inverting mode, i.e. operational or potentiometric, depending on the signal and feedback connections. Other amplifier configurations for specific applications can be obtained by the addition of various circuit components.

The closed loop gain of the amplifier is determined by the value of the feedback impedance and the input impedance. Space is provided on the board for these two gain determining impedances, however, they are often mounted external to the amplifier. Gain switching can be accomplished by external circuits.

SECTION II

OPERATION

A2.1 PRELIMINARY CHECKS

As an integral part of a P.S.C. instrument, the GPA-1 amplifier is prepared with jumpers and/or feedback impedances previous to installation at the factory. When a replacement amplifier is ordered from the factory with reference to a specific instrument and circuit by instrument model and serial numbers and the circuit name, the amplifier can be installed in the instrument for immediate use. However, when a raw amplifier board is obtained from stock, or a board from another instrument is used (where the external-internal circuit wiring may be different), the board must be modified before use. Often, identical circuit configurations are used within an instrument and boards can be readily exchanged.

NOTE

When applicable, a readjustment of the external temperature compensation circuit becomes necessary after changing an amplifier board.

A2.2 CIRCUIT CONFIGURATIONS AND OPTIONS

A simplified block diagram of the basic amplifier board, with input/output terminal connections is shown in figure A2.1. The logic diagram of the instrument in which a particular amplifier is used will show which pins (or functions) are used and in what manner they are connected. Note that various options are provided which may or may not be incorporated in a particular instrument. The instrument logic diagram should be compared with the simplified diagrams showing examples of the various wiring configurations, figures A2.2 through A2.5, to determine which options are used in the instrument. Options are discussed below:

A2.2.1 Voltage Supply Requirements

The amplifier has a basic voltage supply requirement of + and - 24 volts. This can be used to operate the entire amplifier, or as an optional feature, the output stage power can be supplied from another voltage source to take some of the load from the main supply. The output current can be supplied by a lower voltage reducing the dissipation in the output transistors. When a separate supply is used for the output stage, jumpers 2 and 3 are removed, and the voltage is applied to pin 10 (Ext. +) and pin 11 (Ext. -). The external voltage should be

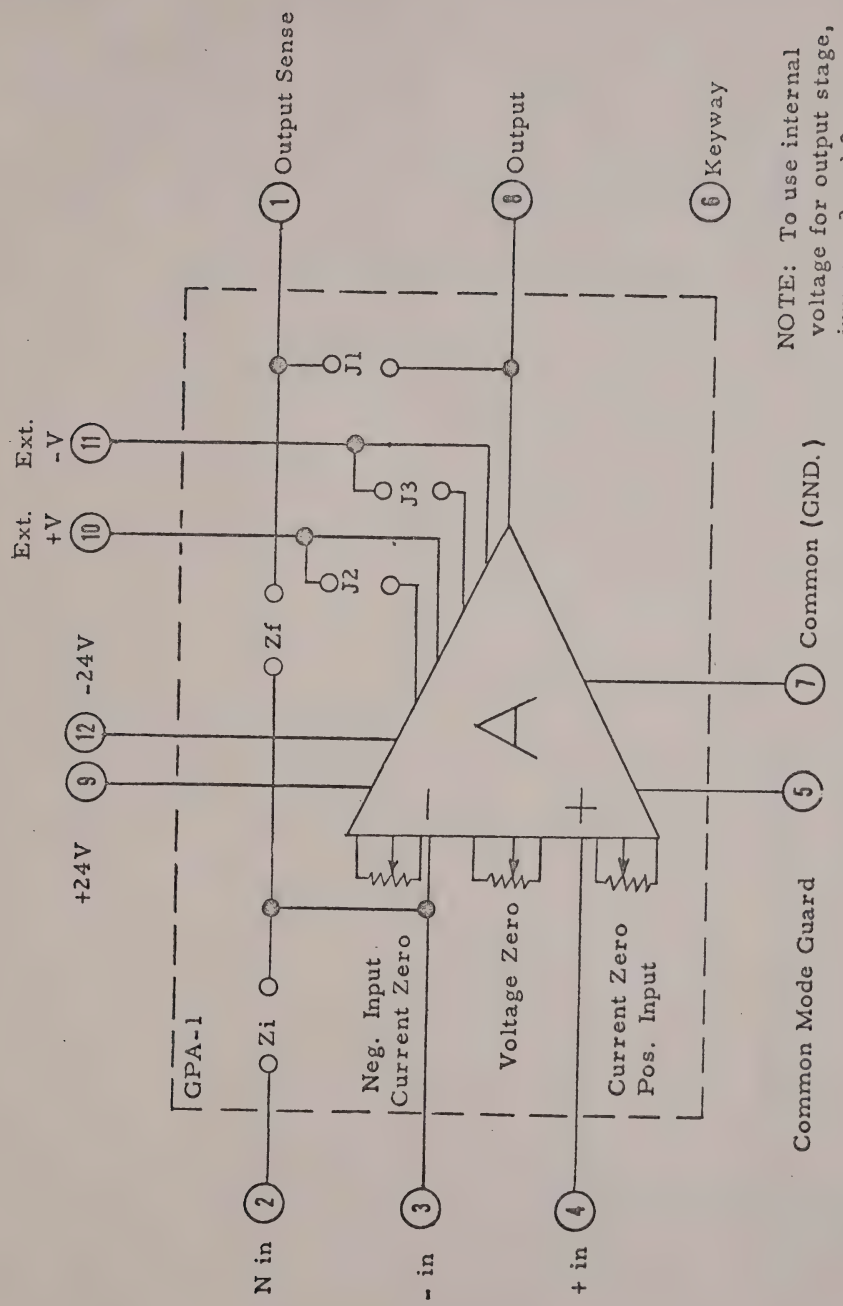


Figure A2. 1 - Block Diagram, GPA-1

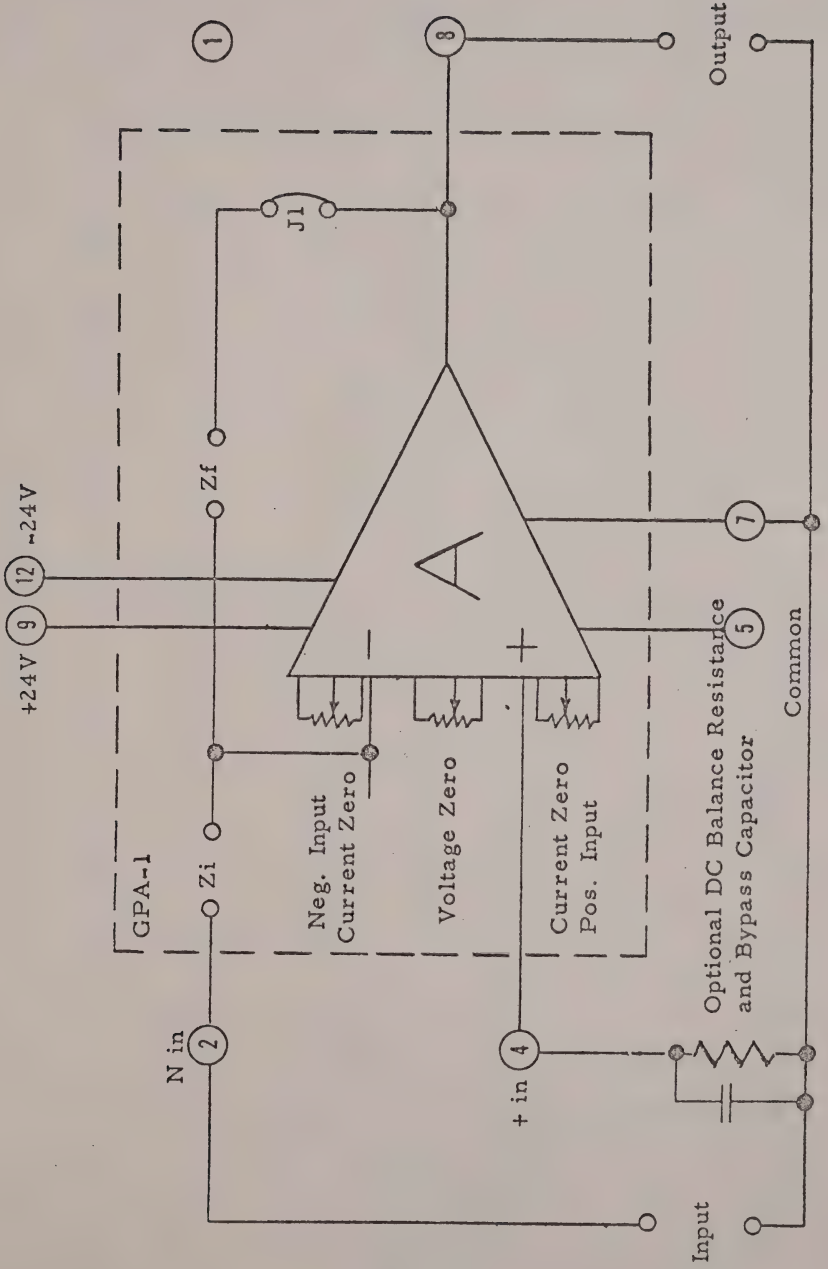


Figure A2.2 - Inverting Amplifier, GPA-1 (Using Gain Determining Impedances on Board)

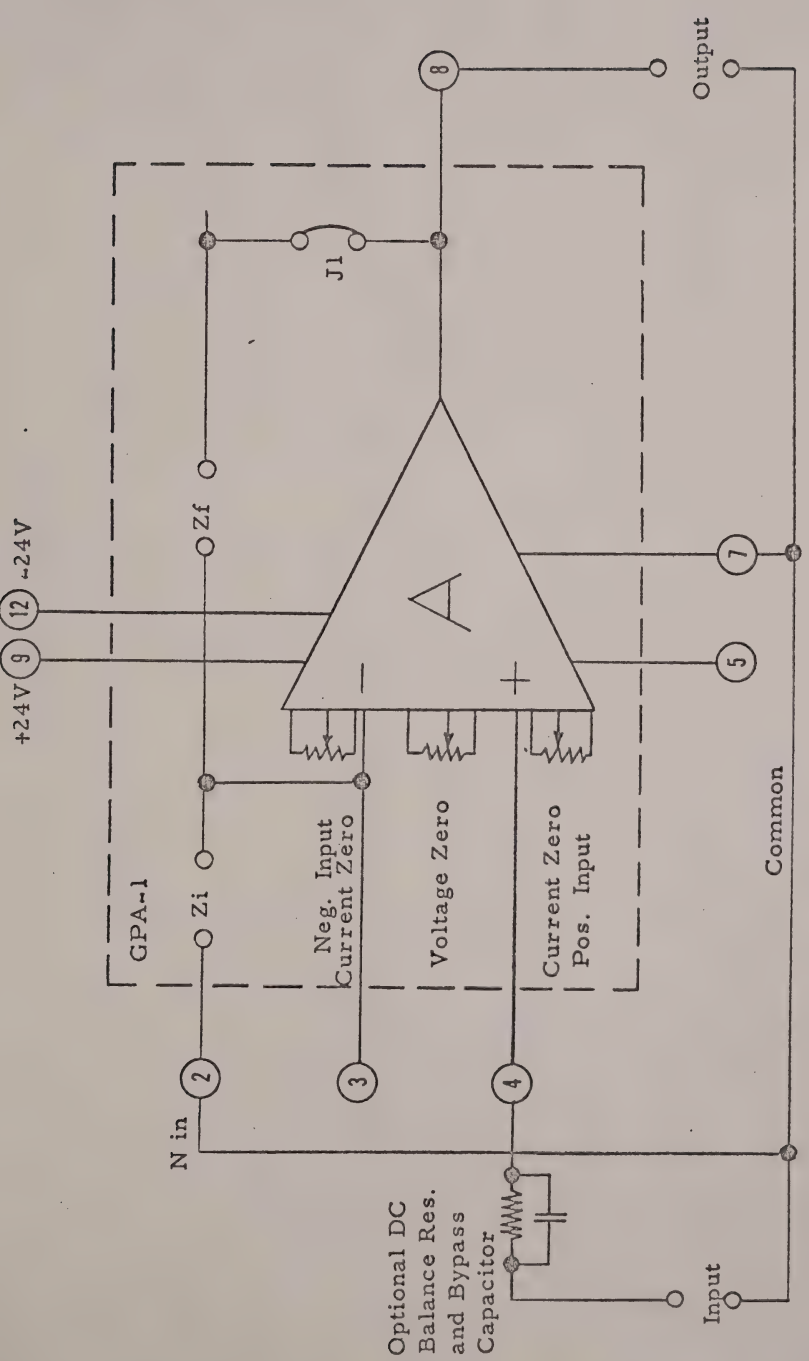


Figure A2.3 - Non-Inverting Amplifier, GPA-1 (Using Gain Determining Impedances on Card)

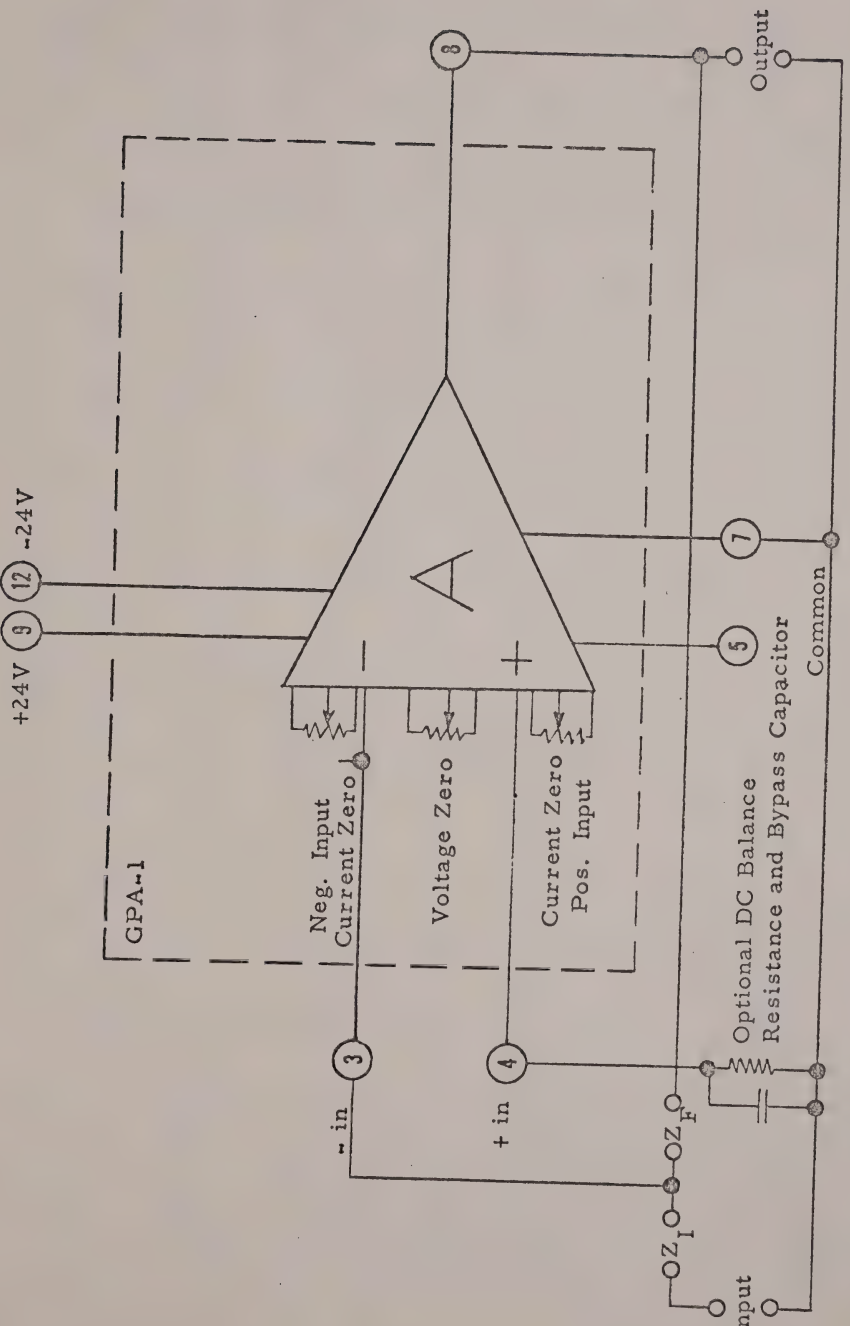


Figure A2.4 - Inverting Amplifier, GPA-1 (Using External Gain Impedances)

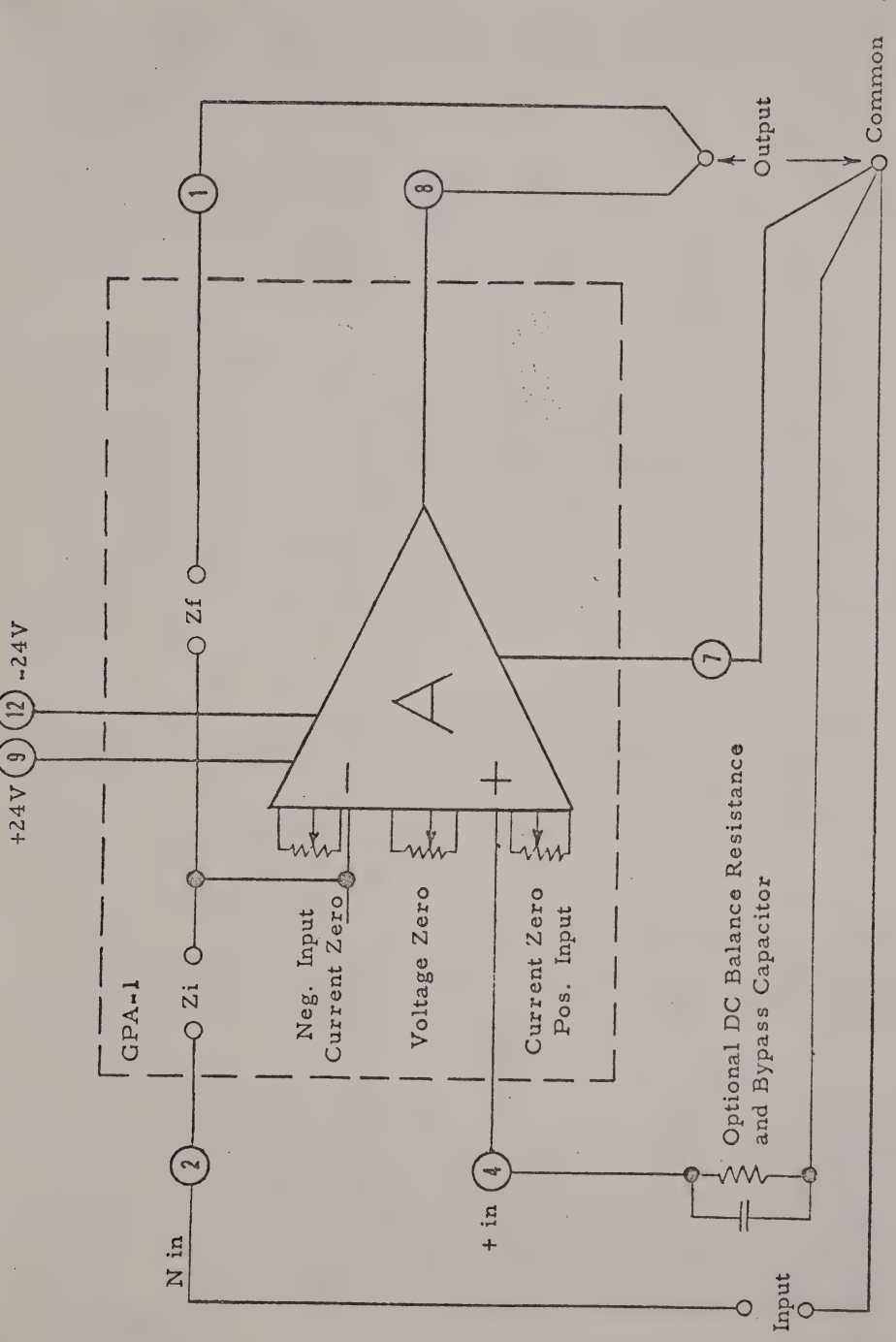


Figure A2.5 - Inverting Amplifier, GPA-1 Remote Sensing (Using Gain Determining Impedances on Card)

±2 volts greater than the maximum amplifier output (not to exceed ±12V). When the amplifier is operated entirely from the + and - 24 volt supplies, the jumpers are installed.

NOTE

Since the supply voltages are not always shown on logic diagrams, it may be necessary to refer to the instrument schematic to determine whether this option is used.

A2.2.2 Feedback Circuits

The feedback circuit can be installed on the board (in spaces provided), or external to the amplifier. The configuration of the feedback circuit determines the amplifier mode (inverting or non-inverting) and the value of the impedances determines the closed loop gain. In the operational mode the gain is approximately $-Z_f/Z_i$; in the potentiometric mode the gain is approximately $1 + Z_f/Z_i$. When the feedback circuit (gain determining impedances) is installed on the board, terminal 2 (N in) is used as the high or low side of the signal input depending on the amplifier mode.

A2.2.3 Remote Sensing

The amplifier output can be wired as a four-wire system by connecting the output sense point, terminal 1, to the high side of the output load and the low side of the input signal to the low side of the output load (common). When this option is used, jumper 1 should be removed. For two-wire output configurations, jumper 1 should be installed. (Refer to paragraph A3.2.4.)

A2.2.4 Common Mode Guard

A common mode guard terminal is provided. This terminal is driven by the amplifier at the common mode voltage and can be connected to an input shield, thus reducing the effects of common signal impedances to ground (refer to paragraph A3.2.3).

A2.3 INSTALLATION

After the appropriate modifications have been performed (if required), the amplifier can be plugged into the circuit. When a temperature compensation circuit is used, ensure that a good thermal bond is maintained between the diode assembly and the input pair transistor heat sink by means of the screws and mounting plate (do not use silicone grease). Readjust the temperature compensation bridge as outlined in Section IV of the instruction manual for the instrument (in which the circuit is used).

SECTION III

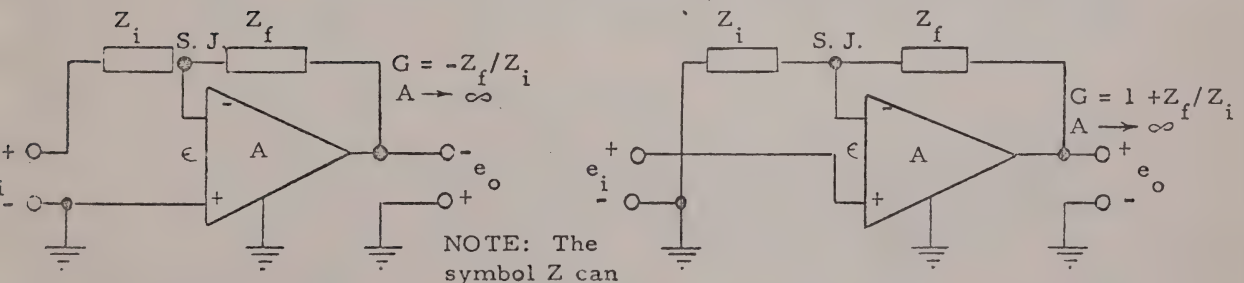
THEORY OF OPERATION

A3.1 PRINCIPLE OF OPERATION - GENERAL

The high open loop gain of the Model GPA-1 General Purpose Amplifier makes it ideally suited for feedback amplifier applications. The two basic feedback amplifiers, inverting (operational) and non-inverting (potentiometric) are illustrated in simplified form in figure A3.1. Each amplifier configuration performs two functions: it determines the polarity of the output signal, and the magnitude with respect to the input (gain). The polarity of the output depends on whether the signal high or signal low side is connected to the + (non-inverting) input of the amplifier. In figure (a), operational configuration, the signal low is connected to the non-inverting input and the signal is inverted. In figure (b), potentiometric configuration, the signal high is connected to the non-inverting input and the signal is not inverted. The closed loop gain of each amplifier is computed using the ratio of the impedances in the feedback loop, as given by the formulas in the illustrations. Derivations of these formulas are given in the following two paragraphs.

NOTE

The value of A is a complex quantity. Also, Z_i and Z_f can be complex, so that G would be complex, However, for purposes of explanation, all symbols are assumed to represent real values.



(a) Operational Amplifier

NOTE: The symbol Z can represent resistance or capacitive on inductive reactance.

(b) Potentiometric Amplifier

Figure A3.1 - Basic Amplifier Configurations

A3.1.1 Operational Mode, Figure A3.1(a)

The input signal applied to the operational configuration is e_i; the differential signal appearing across the amplifier input (summing junction (SJ) to ground) is ϵ, and the output voltage is e_o. The gain of the operational amplifier configuration is called the closed loop gain and is designated by $G = e_o/e_i$. The gain of the amplifier itself is called the open loop gain and is designated by $A = e_o/\epsilon$. Written in another form, the summing junction voltage is $\epsilon = e_o/A$. The open loop gain of the GPA-1 amplifier is approximately 10^6 and can be considered as approaching infinity. Therefore ϵ approaches 0. If the summing junction is considered to be 0 potential, the voltage drops across Z_i and Z_f are e_i and e_o, respectively. By Kirchoff's law, the sum of the currents entering and leaving the summing junction must equal 0. Since the input impedance of the amplifier is very high, little current flows through the input stage, and this current can be neglected (for simplification). Thus, the summation of current at the summing junction is $e_i/Z_i + e_o/Z_f = 0$. Rearranging terms, $e_o/e_i = -Z_f/Z_i = G$, which is the closed loop gain of the amplifier.

A3.1.2 Potentiometric Mode, Figure A3.1(b)

The symbols representing the voltages, impedances and gains are the same as that used in the operational amplifier. Similarly, as in the operational amplifier, ϵ approaches 0 as the open loop gain A approaches infinity. However, in the potentiometric mode, the summing junction voltage (SJ to ground) does not equal ϵ, but equals $\epsilon + e_i$. Since the total voltage applied across the feedback circuit is e_o, the summing voltage can be expressed as $e_o (Z_i/[Z_i + Z_f])$, or $\epsilon + e_i = e_o (Z_i/[Z_i + Z_f])$. Since ϵ approaches 0, it can be neglected. Rearranging terms, $e_o/e_i = 1 + Z_f/Z_i = G$, which is the closed loop gain of the amplifier.

A3.2 INPUT/OUTPUT CONSIDERATIONS

The primary function of a DC amplifier is to reproduce accurately the input signal on a linear scale fixed by the gain. External and internal circuit parameters can influence the desired output, unless provisions are made in the circuit design to compensate for these factors.

A3.2.1 Single-Ended/Differential Inputs

In the GPA-1 amplifier, the input signal e_i is defined as the difference between the input terminals. In the single-ended configuration (illustrated in figure A3.1), this definition is arbitrary, since the input signal is referenced to ground (established by convention). However, if the low side of the input is removed from ground (as in figure A3.2), the input configuration is differential and the difference between the

input terminals is referred to as the normal mode signal. Any signal common to both input terminals with respect to ground is called the common mode signal. Since this signal contains no useful information, it is discarded.

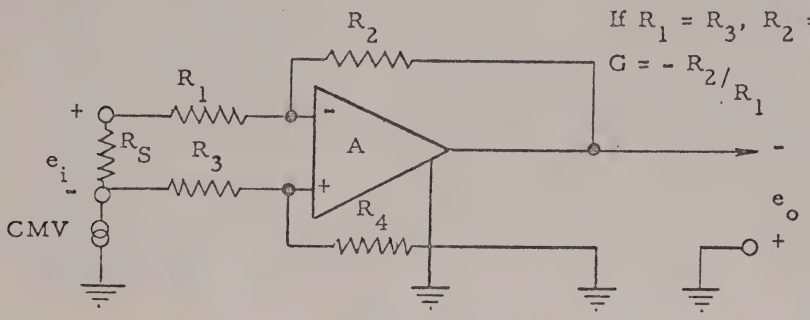


Figure A3.2 - Subtractor (Modified Operational Amplifier)

A3.2.2 Common Mode/Normal Mode

The GPA-1 amplifier exhibits high common mode rejection (approaching infinity), and if the common mode signal is actually common (identically the same) at both inputs, the signal will be eliminated in the amplifier. However, if the common mode signals are not the same at both inputs due to unequal voltage drops between the common mode source and the amplifier inputs, the difference across the inputs will add to the normal mode signal, creating an error. The amplifier cannot distinguish between the normal mode signal and this superimposed error and would amplify both signals if the error were not compensated for by some other means.

In the subtractor (balanced bridge) circuit shown in figure A3.2, the high and low sides of the input signal are applied across voltage dividers to ground. (The amplifier output impedance is very low and can be considered to be at ground for this discussion.) The source of common mode voltage is shown at the low side of the source resistance RS. As current flows in each divider, voltages are developed at the two amplifier inputs. If the dividers are adjusted so that $R_S + R_1 : R_2 = R_3 : R_4$, a voltage null is created at the amplifier input and the amplifier will see only the desired normal mode voltage. The circuit derives its name from the operation performed on the input signal, i.e. it subtracts the voltage of the low input from the high input and amplifies the difference.

A3.2.3 Input Bootstrapping

The GPA-1 has an auxiliary common mode (CM) terminal which can be used to drive an input shield at the common mode voltage. Consider for an example a voltage follower circuit illustrated in figure A3.3. This is a special type of potentiometric amplifier (see figure A3.1(b)), where $Z_i = \infty$ and $Z_f = 0$. By the gain formula, $G = 1 + 0/\infty$ or $G = 1$, and the output should be equal to the input. In addition, the output voltage should follow the input signal variations. In an ideal case, this would be true. However, in some installations, various impedances are present between the input signal line and ground (shown in dotted lines in figure A3.3). This may be due to the proximity of the signal wire to the chassis, or surrounding circuit elements. In either event, these impedances can result in a gain error if the signal source impedance is not zero.

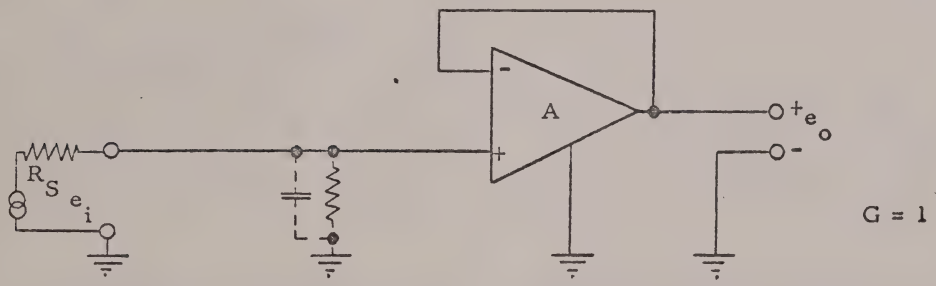


Figure A3.3 - Voltage Follower (Modified Potentiometric Amplifier)

Figure A3.4 shows a method of reducing the effect of signal to ground impedance. By surrounding the input signal line with a voltage equal to that line (driven by the amplifier), no current will flow through the signal to ground impedances and in effect, the signal line will ignore any impedance with respect to ground.

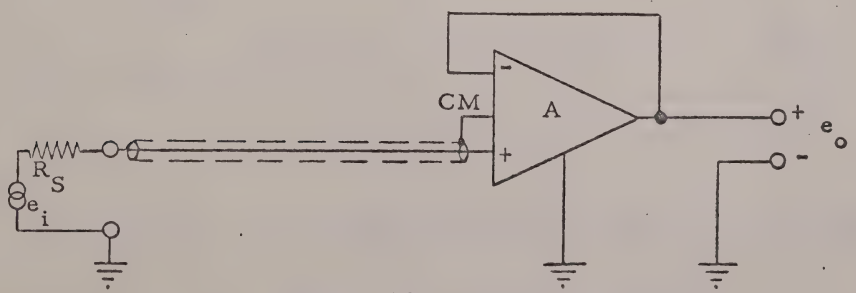


Figure A3.4 - Input Bootstrapping

A3.2.4 Four-Wire Output

In some applications, the resistance of the output signal lines can affect the accuracy of the amplifier. As shown in figure A3.5, the output current creates voltage drops across these resistances, subtracting from the true output (e_o) of the amplifier. This problem can be avoided by locating the output of the amplifier at the actual point of connection to the output load. In effect, this is accomplished by terminating the high side of the feedback loop and the signal low at the load (figure A3.6). These extended (sense) lines draw no load current and sample the output voltage at the load. Thus, the amplifier output is now defined at the point of contact with the load and any voltage drops in line resistances do not affect the overall performance of the amplifier.

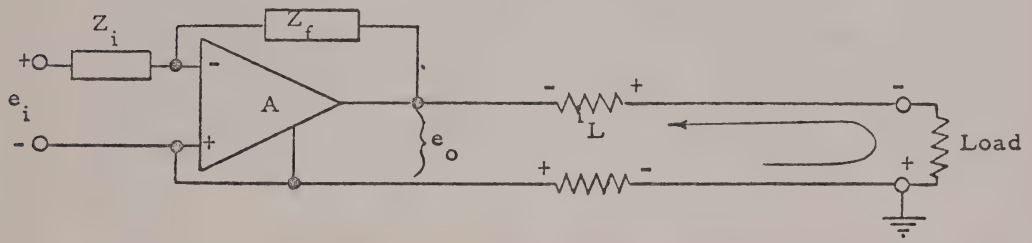


Figure A3.5 - Operational Amplifier (Showing Line Resistances)

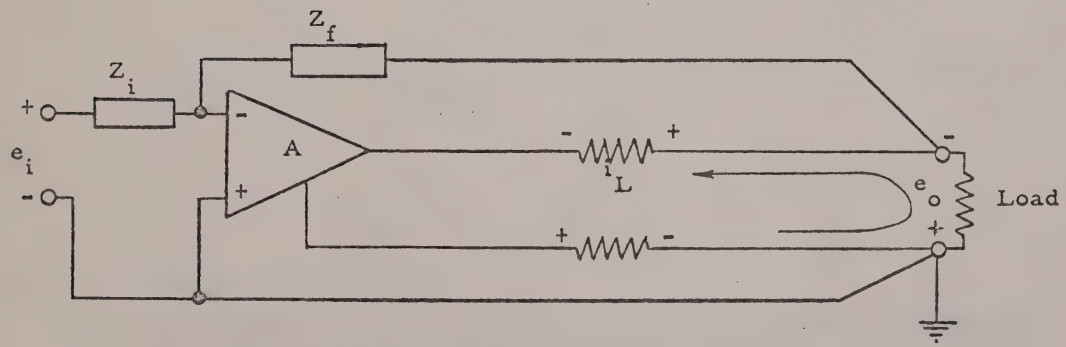


Figure A3.6 - Operational Amplifier (With Four-Wire Output)

A3.2.5 Integration

In certain applications, the amplifier configuration is designed to produce an output proportional to the integral of the input signal. A basic integrator circuit is shown in figure A3.7 with example (ideal) input and output waveforms. The slope and magnitude of the output signal e_o is determined by the RC time constant of the feedback loop by the formula shown. As in the basic operational amplifier (see paragraph A3.1.1) the current into the summing junction equals the current out. The current into the summing junction is $i = -e_i/R_1$ and the current out of the summing junction is $i = dq/dt = C\, de_o/dt$ (by Coulomb's Law). If the two current equations are solved simultaneously for e_o, $e_o = -1/RC \int e_i dt$.

An additional application of an integration type circuit is to attenuate noise superimposed on a DC signal. For this purpose, an operational amplifier with fixed gain determining resistances is used, and a capacitor is installed in parallel across the feedback resistance R_f. This type of circuit has two functions: to provide a fixed DC gain, and to integrate the superimposed noise. Since the integral (or average) of random noise is essentially zero, the circuit effectively attenuates the noise without affecting the DC voltage characteristics.

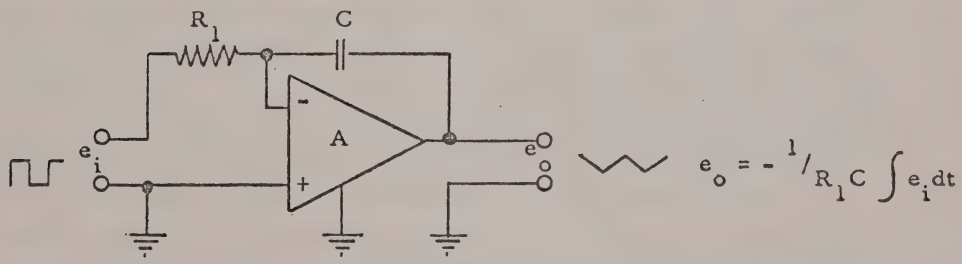


Figure A3.7 - Integrator

A3.3 CIRCUIT DESCRIPTION

For purposes of circuit description, the GPA-1 amplifier is broken down into four basic amplifier sections as shown in figure A3.8. K1 is the differential input amplifier, K2 is the output amplifier, K3 is the common mode amplifier, and K4 is the base current compensating amplifier. The common mode voltage (CMV) is herein defined as the average of the input voltages referred to common, and the normal mode voltage (NMV) is the difference between the inputs.

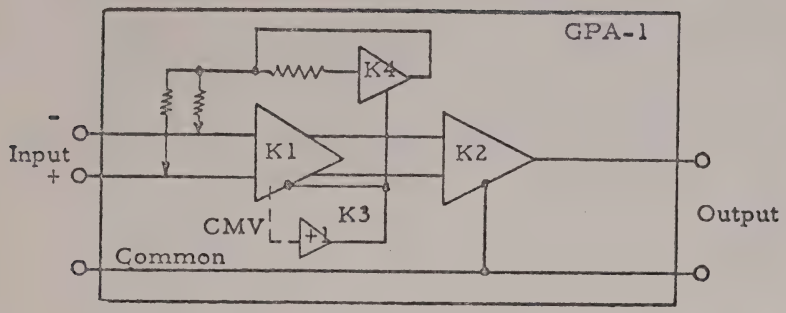


Figure A3.8 - Simplified Diagram - Model GPA-1 General Purpose Amplifier

A3.3.1 General

Amplifier K1 has a differential input and a differential output. The output of amplifier K1 contains the CMV plus the amplified NMV. The entire amplifier K1, as well as amplifier K4, is driven at the CMV by the unity gain amplifier K3. Amplifier K2 attenuates the CMV while continuing to amplify the NMV. Amplifier K2 provides the necessary voltage and current excursions at the output.

A3.3.2 Amplifier K1

Amplifier K1 includes differential stages Q4, Q5 (Q9-Q10) and (Q14-Q15) which amplify NMV signals applied across the amplifier input (see schematic). All transistor terminals (emitter, base, collector) of these stages are driven at the CMV by the common mode amplifier K3 or are allowed to follow the common mode voltage by being returned to a supply through a current source. This results in very little of the CMV being converted into a NMV in these stages.

Resistors R16, R17, R25 and capacitors C10, C11, C3, C4 and C5 control the frequency response of the differential amplifier. Diodes CR2 and CR3 protect the input transistors from being damaged by overload.

A3.3.3 Amplifier K2

Amplifier K2 includes transistors Q16, Q17, Q18, Q19, Q20 and Q21. The amplifier receives the amplified NMV and the CMV (which has not been amplified) at the differential stage Q16 and Q17. Because the emitters of this stage are supplied with current by a constant current transistor Q18, this stage attenuates the CMV. The current changes developed in Q17 from the NMV are transferred to transistor Q22 which is sufficiently removed from the common (ground) level

to provide the necessary output voltage swing at the collector. Constant current transistor Q19 provides a return to the minus supply for the collector current of Q22. Transistor Q20 supplies load current out of the amplifier and transistor Q21 receives load current into the amplifier. Diodes CR9 and CR10 and resistors R51 and R52, in conjunction with the V_{be} drops of transistors Q20 and Q21, limit the maximum load current. Resistors R47 and R49 and capacitor C8 control the frequency response of the output amplifier.

Offset voltage originating in the input stages is cancelled by adjustment of potentiometer R27. Offset voltages outside the range of this potentiometer are accomodated by selection of resistor R26.

A3. 3. 4 Amplifier K3

Amplifier K3 consists of two emitter followers, transistors Q6 and Q8. The input of the amplifier is the CMV at the emitters of the input stage transistors, Q4A and Q4B. The output drives differential amplifier K1 and amplifier K4 at the CMV. The power supplied to amplifiers K1 and K4 comes from a voltage source and several current sources. The voltage source appears between the emitters of transistors Q11 and Q8. Zener diode CR6 receives its current from the constant current source, transistor Q12, and the current is buffered from the differential stages' load current by transistor Q11. Transistor Q7 provides a constant current for the input stages Q4 and Q5. Transistor Q13 maintains a constant current through differential stage Q9 and Q10.

A3. 3. 5 Amplifier K4

Amplifier K4 includes transistors Q1, Q2 and Q3, and provides temperature compensated base currents to the input stage. These currents cancel the offset currents and are supplied through potentiometers R6 and R7 and resistors R9 and R10.

A3. 3. 6 Constant Current Supplies

The GPA-1 amplifier does not require regulated voltage supplies. The amplifier has a built-in insensitivity to supply voltage ripple or slow voltage variations. Zener diode CR5 supplies a constant voltage for constant current transistors Q7, Q13, Q18 and Q19. Since the voltage across the emitter resistors of these transistors (the Zener voltage minus the V_{be} of the transistor) is constant even with line variations, the current through the transistors will also be constant. Zener diode CR8, in conjunction with resistors R37 and R38 and diode CR7, maintains a constant voltage across resistor R36. This forces transistor Q12 to provide a constant collector current.

SECTION IV
CALIBRATION

A4.1 GENERAL

The calibration procedure should be performed prior to the test procedure outlined in paragraph A5.3 and subsequent to any corrective maintenance. Calibration of the Model GPA-1 amplifier consists of adjusting three trimpots for proper DC balance (paragraph A4.4). To perform the calibration procedure, the amplifier must be removed from associated circuitry and be checked under controlled conditions. The operating conditions for the calibration and test procedures are controlled by a special test fixture. The test fixture can be built in the field (using standard components), or can be obtained from Electro Instruments, available on special order. A schematic diagram for an improvised test fixture is illustrated in figure A4.1.

NOTE

For field installations not requiring rigid tolerance specifications, a modified test fixture providing for a less rigorous calibration procedure is described in paragraph A4.5.

A4.2 CONSTRUCTION OF TEST FIXTURE

It should be possible to obtain all parts for the improvised test fixture from a local distributor. Construction details are outlined below:

1. Use a metal chassis for maximum shielding.
2. Mount the power transformer greater than 10" from the plug-in receptacle.
3. Mount switches $+R_i$ and $-R_i$ close to the plug-in receptacle.
4. Mount all switch parameter resistors on switches.
5. Install a shield plate behind the front panel switches.
6. Keep all leads as short as possible.
7. Common leads should be size No. 22 or greater.
8. Tie all common leads to one common point near pin 7 of the plug-in receptacle terminal strip.
9. All voltage leads should be as far removed from terminal strip as possible.

T1: Triad F90X or equivalent
M1: ±50 microamps full scale from center zero, 1 kilohm meter movement, (different resistance value can be used with appropriate multiplier resistors)
CR1 and CR2: 10 to 12V Zener diodes
Plug-in Receptacle (Circled Pin Numbers): Cinch 250-12-30-170 or equivalent

Resistors are carbon, 1/4 watt, 5% except where otherwise specified.
Capacitors should have 20% tolerance; in power supply the capacitors should have a voltage rating of 50V or more.
Diodes are standard silicon type; in power supply the diodes should have a voltage rating of 50V or more.

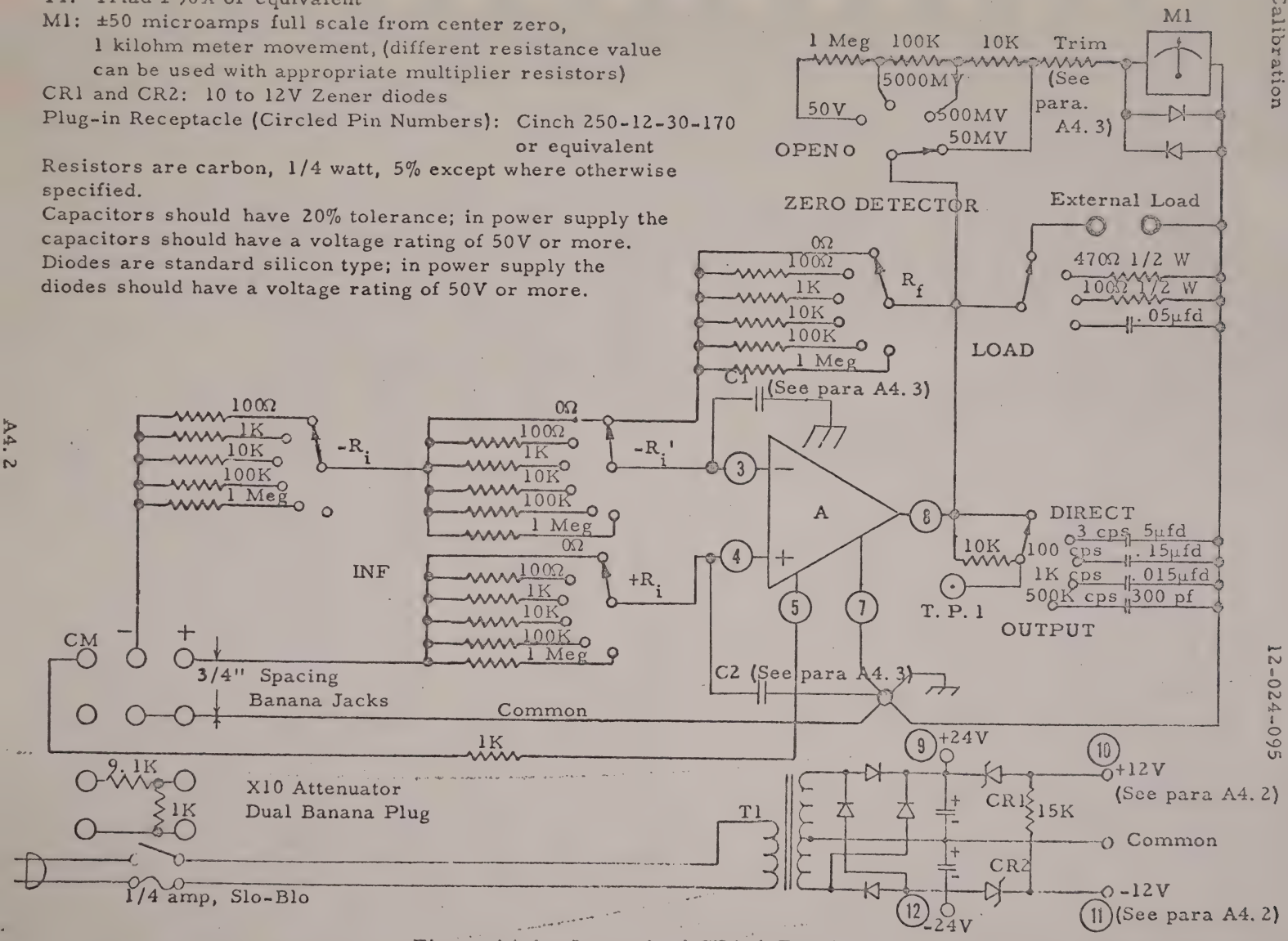


Figure A4. 1 - Improvised GPA-1 Test Fixture

i. Set the LOAD switch to External Load and the ZERO DETECTOR switch to 50MV. Connect a jumper across the points labeled "trim" in figure A4. 1. If a meter with an internal resistance of 1K was used, the meter should read +50 millivolts. If the meter does not read 50 millivolts, use a resistor substitution box in place of the jumper to determine the value of the trim resistor required. Install a trim resistor and check that the meter reads 50 millivolts.

A4. 4 OFFSET ADJUSTMENTS

The calibration procedure for the amplifier offset adjustments is outlined below. If the amplifier cannot be calibrated, refer to paragraph A5. 5

a Set front panel controls as follows:

$+R_i$	0Ω
$-R_i$	100Ω
$-R_i'$	0Ω
R_f	100K
OUTPUT	DIRECT
ZERO DETECTOR	OPEN
LOAD	External Load

b. Connect shorting plugs from + and - input terminals to common. Plug amplifier board into fixture and turn power on. Allow 15 minutes warmup time.

c. Set the ZERO DETECTOR switch to the 50MV position. Set the voltage offset adjustment R27 on the amplifier (figure A4. 2) for a meter deflection with ±2 millivolts.

d. Set the negative input current offset adjustment R7 for minimum zero meter deflection while switching $-R_i'$ from 0Ω to 100K. Return $-R_i'$ to 0Ω.

e. Set the positive input current offset adjustment R6 for minimum zero meter deflection while switching $+R_i$ from 0Ω to 100K. Return $+R_i$ to 0Ω.

f. Recheck the meter deflection for ±2 divisions of zero. If necessary, set the voltage offset adjustment R27 for ±2 millivolts on the meter. Return the ZERO DETECTOR switch to the OPEN position.

A4.5 ALTERNATE CALIBRATION PROCEDURE

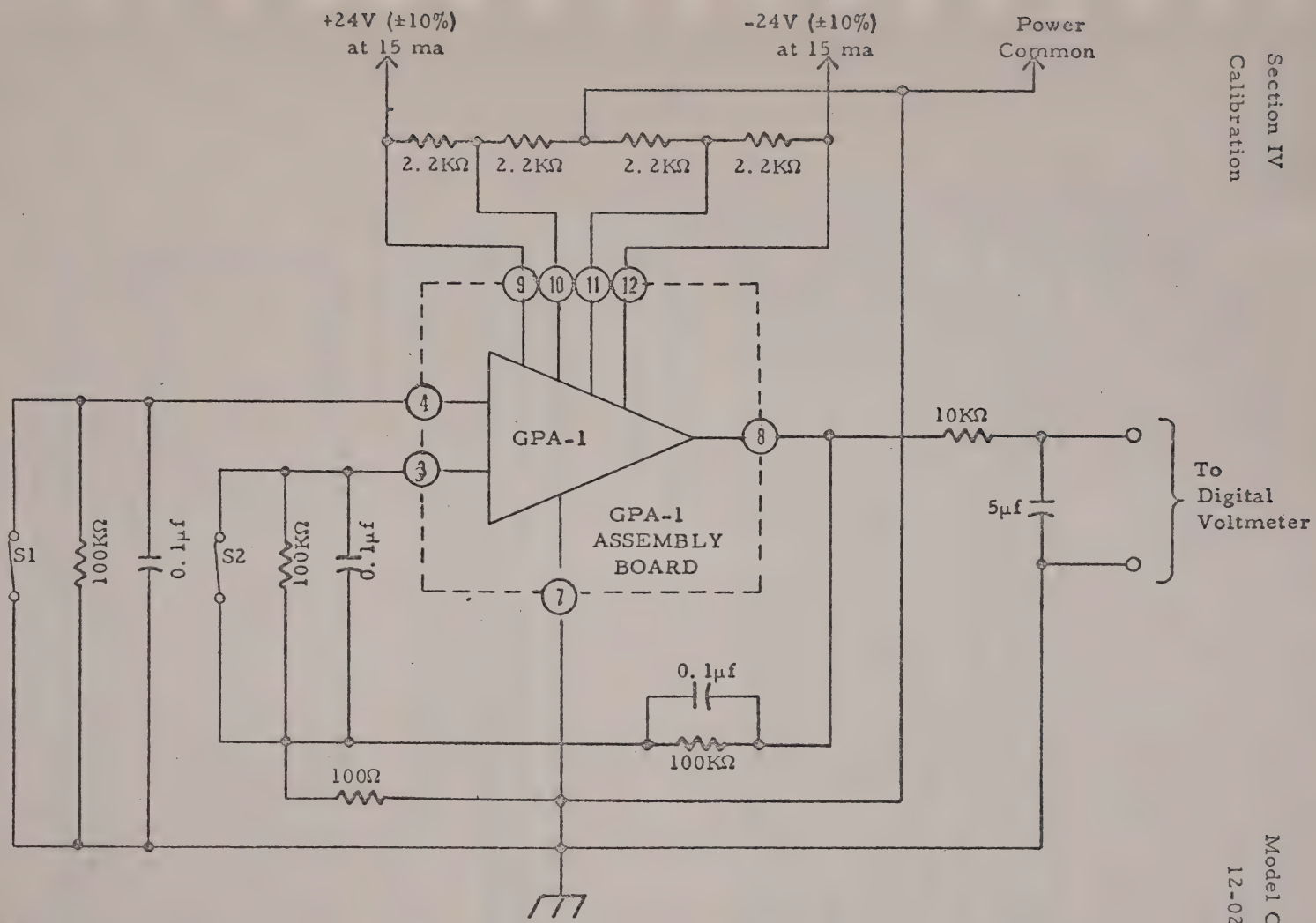
An alternate test fixture is illustrated in figure A4.3. The setup does not provide for all of the maintenance checks outlined in section V, however it does allow for adjustment of the calibration potentiometers on the GPA-1 assembly board. A precision 5-digit digital voltmeter with an accuracy of .01% or better should be used to monitor the output voltage of the amplifier - test fixture configuration. The procedure is outlined below:

a. Close S1 and S2. Set the Voltage Offset Adjustment (figure A4.2) for an output of less than 10 mv, as monitored on the digital voltmeter. Note this level as the zero reference.

b. Open S1. Set the Positive Input Current Offset Adjustment to the zero reference level noted in step a above.

c. Close S1 and open S2. Set the Negative Current Offset Adjustment to the zero reference level noted in step a.

d. Recheck steps a, b and c above.



NOTE: All resistors 1/2 W, 5% and all Capacitors mylar, 20%.
Numbered terminals correspond to terminals on assembly board connectors
Mating connector is a Cinch 250-12-30-170.

SECTION V
MAINTENANCE

A5.1 GENERAL

The Model GPA-1 requires no periodic maintenance. The amplifier can be operated continuously without any adverse effect on its life. If a malfunction is evident, first calibrate the amplifier as outlined in paragraph A4.4. If the amplifier cannot be calibrated, i.e. if the offset adjustments do not provide sufficient range to correct the offsets, refer to paragraph A5.5. After the amplifier is properly calibrated, perform the test procedure outlined below. Performance of these checks will either (1) verify that the amplifier is operating within allowable tolerances, or (2) help isolate the malfunction as an aid to trouble analysis. In the first case, the amplifier should be returned to the circuit from which it came. If a malfunction continues to exist, the surrounding circuitry is at fault. In the second case, corrective maintenance should be performed as outlined in paragraph A5.4.

A5.2 TEST EQUIPMENT REQUIRED

a. GPA-1 Test Fixture

b. VTVM

c. Oscilloscope with a DC sensitivity of at least 1 mv/cm.

d. Sine wave generator, 100 cps minimum to 500KC, at least 25 volts peak-to-peak output, and a maximum output impedance of 1K, such as a Hewlett-Packard Model 200CD.

e. X10 attenuator dual banana plug (see figure A4.1).

A5.3 TEST PROCEDURE

a. Set front panel controls of test fixture as follows:

$+R_i$	0Ω
$-R_i$	10K
$-R_i$,	0Ω
R_f	100K
OUTPUT	DIRECT
ZERO DETECTOR	OPEN
LOAD	470Ω

b. Plug amplifier board into test fixture and turn power on. Allow 15 minutes warmup time. Connect oscilloscope from T.P. 1 on the fixture to common. Monitor all steps.

c. Connect the generator from the - input terminal to ground. The + input terminal should be shorted to ground.

d. Set the generator for a frequency of 5KC. Set the generator output voltage for 24V P/P. The sine wave peaks should not be clipped.

e. Change the generator frequency to 100 cps. Set the LOAD switch to 100Ω. Increase the generator output until the amplifier output clips. The peak amplitude should be between 2 volts and 3.5 volts.

f. Change the generator frequency to 1KC. Set the LOAD switch to .05 mfd. Increase the generator output to an amplifier overload condition and return. The amplifier should recover. Return the LOAD switch to External Load.

g. Set the front panel controls of the test fixture as follows:

$+R_i$	0Ω
$-R_i$	1NF
$-R_i$'	0Ω
R_f	0Ω
OUTPUT	DIRECT
ZERO DETECTOR	OPEN
LOAD	External Load

h. Connect the X10 attenuator dual banana plug between the + input terminal and common.

i. Connect the generator from the + input terminal of the dual banana plug connector to common. Set the frequency for 1KC.

j. Set the oscilloscope for a sensitivity of .01V/cm and AC coupling.

k. Adjust the generator for an amplitude of .03V P/P appearing at the output of the amplifier.

l. Center the signal waveform to the center of the scope face. Increase the generator frequency while monitoring the amplifier output. There may be an increase in amplitude between 100KC and 500KC. The signal should not exceed .04V P/P. At 500KC the wave shape should not be distorted and the amplitude should not decrese below .02V P/P of the 1KC setting.

A5.4 CORRECTIVE MAINTENANCE

If the amplifier does not respond properly to the test procedure, the following steps should be followed:

a. Remove the board from the test fixture and check for solder shorts across the printed circuit straps.

b. Re-insert the board in the test fixture and set the front panel controls as follows:

$+R_i$	0Ω
$-R_i$	1NF
$-R_i'$	0Ω
R_f	0Ω
LOAD	External Load

c. Connect shorting plugs from + and - input terminals to common.

d. The amplifier is now set up in a condition from which the voltage levels appearing on the schematic were taken. Check the voltages on the amplifier board against the voltages shown on the schematic. Refer to paragraph A3. 3 for circuit description and use standard troubleshooting techniques to locate the malfunction. Since each amplifier is tested and calibrated prior to shipment, the following assumptions should be made in troubleshooting:

1. The amplifier is wired correctly.
2. Transistor troubles are usually limited to: open, short, and noisy.
3. Diode failures are: open and shorted.
4. Resistors become open or increase in value.
5. Capacitors can be open or shorted.

e. When a faulty component is found, use an exact replacement or equivalent part. If a single transistor of a matched pair is bad, replace both transistors with a matched pair. If any component is changed, repeat the calibration procedure.

A5. 5 REPLACEMENT OF TRIM RESISTORS

Trim resistors are selected at the factory and normally do not require replacement. However, if the offset adjustments do not provide sufficient range to calibrate the instrument (paragraph A4. 4), or if transistor Q1, Q4 or Q5 is replaced or the associated circuit otherwise misaligned, it may be necessary to replace one or both trim resistors. The procedure for selection of trim resistors is outlined below.

A5. 5. 1 Current Offset Trim Resistor R3'

a. Set the voltage offset adjustment R27 to mid-position (12-1/2 turns from end stop).

b. Set front panel controls of test fixture as follows:

$+R_i$	0Ω
$-R_i$	INF
$-R_i'$	0Ω
R_f	0Ω
OUTPUT	DIRECT
ZERO DETECTOR	OPEN
LOAD	External Load

c. Connect shorting plugs from + and - input terminals to common. Plug amplifier board into fixture and turn power on. Allow 15 minutes warmup time.

d. Connect the VTVM from the amplifier board test pin to common. If the test point voltage is between +.75V and +.90V, it will not be necessary to replace R3'. It will be necessary to replace the trim resistor R3' only if the test point voltage is less then +.75V or greater than +.90V.

e. If the test point voltage is out of the limits described in step d, remove R3' from the amplifier board and solder a temporary jumper across the points of connection for R3'. (See figure A4.2.)

f. Refer to table A5.1. The voltage at the test point subtracted from +.8V is the E_1-E_2 value and should be used to select resistor R3' from the table. The closest stock value should be installed on the board. Replacement resistor should be 1/4 watt, composition, 5% tolerance.

g. If the initial voltage happens to be above +.8 volts, the 10 megohm resistor R3 should be replaced with a 5.6 megohm resistor. The formula for finding R3' is:

$$\frac{(E_1 - E_2)\, R_3}{E_2}$$

E_1 = +.8 volts
E_2 = measured voltage appearing at test pin
R_3 = 10 megohm or 5.6 megohm

h. After the trim resistor is installed, recheck the voltage at the test point. The allowable limits are between +.75 volts and +.90 volts.

Table A5.1 - Selection of R3' (R3 = 10 megohm)

$E_1 - E_2$	R_3'
.1 Volt	1.5 megohm
.15 Volts	2.4 megohm
.20 Volts	3.3 megohm
.25 Volts	4.7 megohm
.30 Volts	6.2 megohm
.35 Volts	7.5 megohm
.40 Volts	10.0 megohm
.45 Volts	12.0 megohm
.50 Volts	15.0 megohm

A5.5.2 Voltage Offset Trim Resistor R26

a. Set front panel controls of test fixture as follows:

$+R_i$	0Ω
$-R_i$	100Ω
$-R_i'$	0Ω
R_f	100K
OUTPUT	DIRECT
ZERO DETECTOR	OPEN
LOAD	External Load

b. Set the ZERO DETECTOR switch to successively lower resistance positions until the meter deflection is mid scale or greater. Since the amplifier is set up for a gain of X1000, the amount of voltage offset is determined by the meter reading in millivolts divided by 1000. This is the same as reading the voltage offset directly in microvolts.

c. If the ZERO DETECTOR switch is now in the 50MV or 500MV positions and the meter reads less than full scale, repeat the calibration procedure (paragraph A4.4). If the meter reads full scale, or greater, or if the ZERO DETECTOR switch is in another position, remove the current offset trim resistor R26 from the amplifier board.

d. Refer to table A5.2 and select the trim resistor corresponding to the measured offset. The replacement resistor should be an eighth-watt, metal film type, 1% tolerance, T8 or T9 temperature coefficient (RN60E).

Table A5.2 - Selection of R26

Measured Offset	R26
0μv to ± 500μv	NONE
±500μv to ±1000μv	249K
±1000μv to ±1500μv	124K
±1500μv to ±2000μv	88.5K
±2000μv to ±2500μv	61.9K
±2500μv to ±3000μv	49.9K
±3000μv to ±3500μv	41.2K

e. Refer to figure A5.1. If the offset is positive, the select resistor is installed across area No. 1. If the offset is negative, the select resistor is installed across area No. 2.

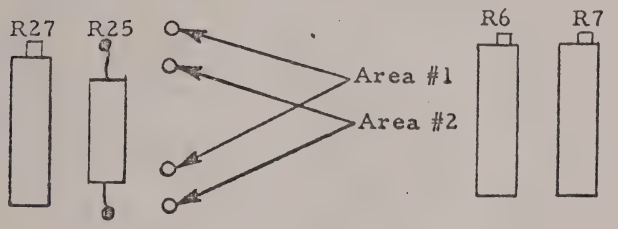
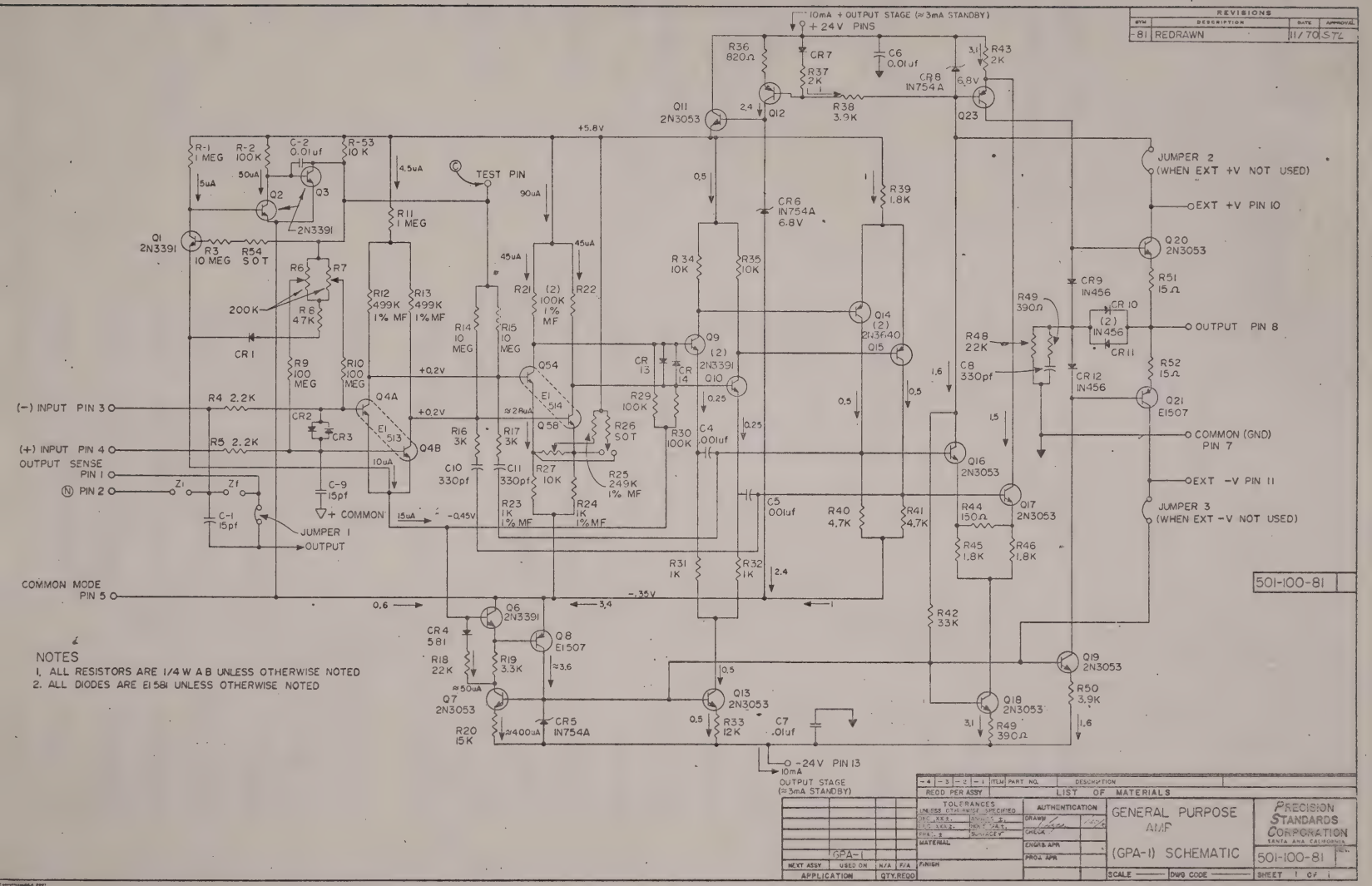


Figure A5.1 - Location of Trim Resistor R26

f. Repeat the calibration procedure (paragraph A4.4).



NOTES
1. ALL RESISTORS ARE 1/4 W AB UNLESS OTHERWISE NOTED
2. ALL DIODES ARE E1581 UNLESS OTHERWISE NOTED

REVISIONS			
BTM	DESCRIPTION	DATE	APPROVAL
-81	REDRAWN	11/70	STZ

-4	-3	-2	-1	ITEM	PART NO.	DESCRIPTION
REQD PER ASSY				LIST OF MATERIALS		

TOLERANCES UNLESS OTHERWISE SPECIFIED
DEC. XX ± .1
DEC. XXX ± .02
FRAC. ± 1/64
MATERIAL
FINISH

AUTHENTICATION
DRAWN
CHECK
ENGR'G APPR
PROJ. APPR

GPA-1
NEXT ASSY | USED ON | N/A | F/A
APPLICATION | QTY. REQD

GENERAL PURPOSE AMP
(GPA-1) SCHEMATIC

PRECISION STANDARDS CORPORATION
SANTA ANA CALIFORNIA

501-100-81

SCALE | DWG CODE | SHEET 1 OF 1

PRECISION Standards CORP.
1701 REYNOLDS, SANTA ANA, CALIF. 92705

GPA-I AMPLIFIER

REPLACEMENT PARTS LIST

Reference	Description	Stock Number
Q1,Q2,Q3,Q6,Q9,Q10	Transistor, 2N3391	91-33-910
Q4	Dual, Xsistor 513	94-60-230
Q5	Dual, Xsistor 514	94-60-240
Q7,Q11,Q13,Q16,Q17,Q18 Q19,Q20	Xsistor, 2N3053	91-30-530
Q8	Xsistor, 507	94-58-507
Q14,Q15	Xsistor, 2N3640	91-36-400
CR1,CR2,CR3,CR4,CR7	Diode, 581	94-45-581
CR5,CR6,CR8	Diode, Zener 1N750A	92-07-541
CR9,CR10,CR11,CR12	Diode, 1N456	92-04-560
C8,C10,C11	Capacitor, Silver Mica, 330pf	53-21-331
C1,C9	Capacitor, Corning, 11mmfd	51-19-150
C2,C6,C7	Capacitor, Ceramic, .01uf	48-30-103
C4,C5	Capacitor, Ceramic, .001uf	48-10-102
R52	Resistor, 1/4W, 5%, 18 ohm	86-04-188
R51	Resistor, 1/4W, 5%, 22 ohm	86-04-196
R94	Resistor, 1/4W, 5%, 150 ohm	86-04-280
R31,R32	Resistor, 1/4W, 5%, 1K ohm	86-04-364
R44,R44,R45,R39	Resistor, 1/4W, 5%, 1.8K ohm	86-04-388
R36	Resistor, 1/4W, 5%, 820 ohms	86-04-356
R49	Resistor, 1/4W, 5%, 390 ohms	86-04-324